Puget Sound

Trajectory Analysis Planner (TAP) Technical Documentation

Caution: Before installing TAP Program, note system requirements inside front cover.

Washington Department of Ecology
Spill Prevention, Preparedness, and Response Program
July 2003

Publication #03-08-007

Printed on recycled paper.

Abstract

Abstract

The Puget Sound Trajectory Analysis Planner (TAP) is a computer-based tool that investigates the probabilities that spilled oil will move and spread in particular ways within a particular area. TAP does this by assessing hundreds of site-specific spill trajectories. The Puget Sound TAP Technical Document describes the TAP methodology and trajectory modeling behind TAP, as well as the accuracy and limitations of TAP.

System requirements for installing TAP program
The Puget Sound TAP program, installation instructions, and user manual are located on the CD - *Puget Sound Trajectory Analysis Planner (TAP) Technical Documentation, software, User Guide and Appendices (July 2003).*
Ecology publication number: 03-08-008.

CAUTION: Requires approximately five gigabytes of memory to install and run.

For copies of this publication, contact:

Washington Department of Ecology
Spill Prevention, Preparedness,
and Response Program
P. O. Box 47600
Olympia, WA 98504-7600
(360) 407-7455
FAX: (360) 407-7288

This and other Spills Program publications are available online at:
http://www.ecy.wa.gov/biblio/spills.html

For more information on the Spill Prevention, Preparedness, and Response Program, visit our Website at: http://www.ecy.wa.gov/programs/spills/spills.html

Puget Sound

Trajectory Analysis Planner (TAP) Technical Documentation

Caution: Before installing TAP Program, note system requirements inside front cover.

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Washington Department of Ecology
Spill Prevention, Preparedness, and Response Program
July 2003

Publication #03-08-007

Printed on recycled paper.

Acknowledgements

The Washington State Department of Ecology, assisted by the NOAA Office of Response and Restoration, Hazardous Materials Response Division, and the Washington State Department of Fish and Wildlife, developed the Puget Sound TAP. The Department of Ecology gratefully acknowledges the efforts of the Department of Fish and Wildlife in initiating the development of a TAP for Puget Sound. The Puget Sound region presents a diverse and challenging modeling environment. As such, the Department of Ecology is greatly indebted to NOAA for developing the TAP program and their great diligence in properly overseeing work on this project. Additional gratitude is extended to the following: Al Wallis, National Climatic Data Center (NCDC), for providing most of the wind station data; Mark Albright, University of Washington, Atmospheric Science Department for providing ferry wind data; The National Data Buoy Center (NDBC) for providing wind data; The National Weather Service, Seattle, Washington for answering a multitude of questions concerning wind data throughout the Puget Sound basin; Environment Canada, Hydrology Department for providing Fraser River Data; and the United States Geological Service (USGS) for providing U.S. hydrology data. Barbara Hickey (University of Washington), Curt Ebbesmeyer (Evans-Hamilton Inc.), William Crawford (Environment Canada) and Richard Thomson (Institute of Ocean Sciences) are acknowledged for their consultation when modeling currents in and around the Strait of Juan De Fuca.

Writing and review team:

David Mora, Washington Department of Ecology
Glenn Watabayashi, NOAA
Marc Hodges, NOAA
David Heimer, Washington Department of Fish and Wildlife

Editing and layout: Mariann Cook Andrews, Ecology

Table of Contents

Puget Sound Trajectory Analysis Planner (TAP)
Technical Documentation

1 BACKGROUND

The Trajectory Analysis Planner (TAP) is a computer-based tool that investigates the probabilities that spilled oil will move and spread in particular ways within a particular area. It was developed by NOAA's Office of Response and Restoration Hazardous Materials Division. TAP is a **planning** tool, **not** an oil spill response model. TAP will not tell you how a particular oil spill in the future will move. What it will do is estimate the probability of where spilt oil will go by assessing hundreds of site-specific spill trajectories. The Puget Sound TAP features approximately 200 start sites. 500 spill trajectories were derived for each site and for each of three seasons, based on historical geophysical data. The general purpose of the Puget Sound TAP project is to improve spill contingency planning efforts.

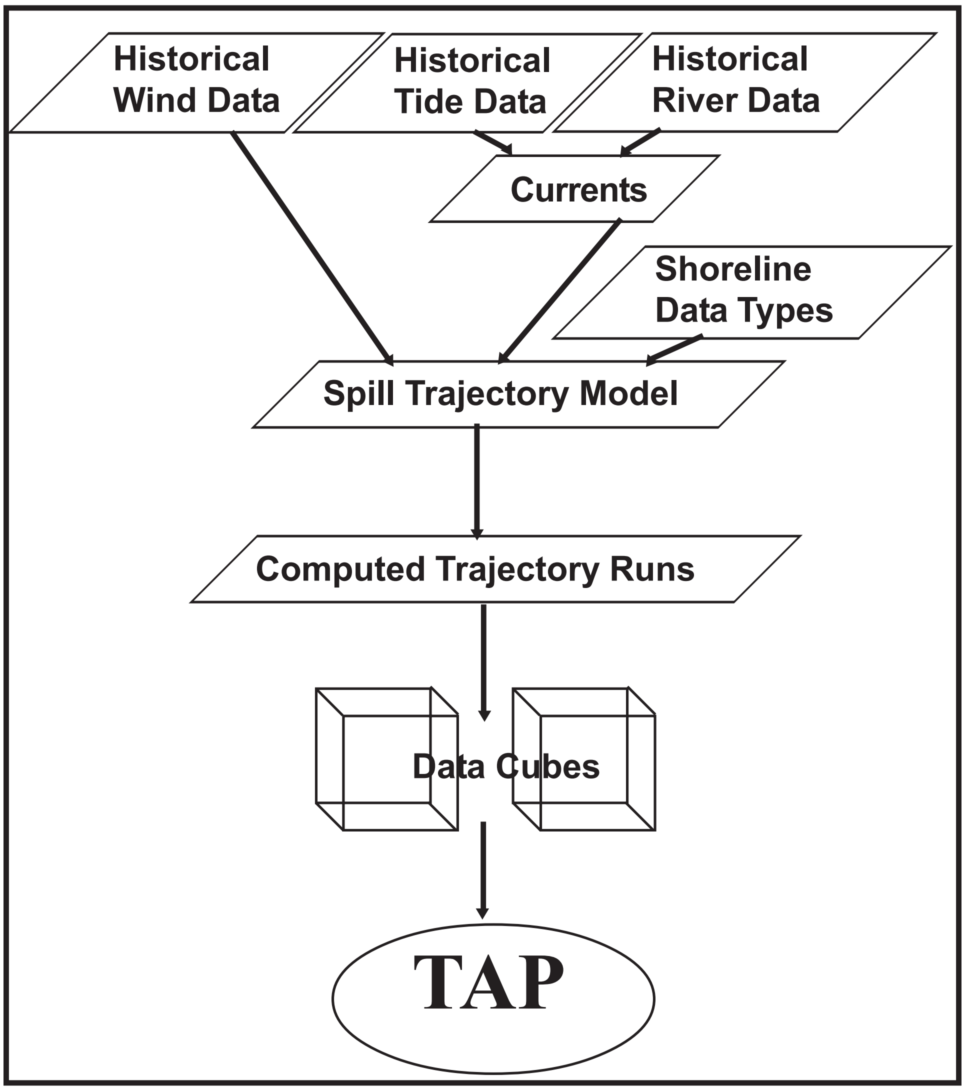


Figure 1. TAP Process Diagram, showing shoreline type, wind, and current data inputs used by an oil spill simulation model to generate spill trajectory output data (cubes).

2 TAP METHODOLOGY

TAP must process data from a large number of individual trajectories to provide statistics of oil spill movement. Each trajectory is calculated using a unique set of hydrologic, oceanographic, and meteorological conditions. Figure 1 depicts the process used when creating a TAP, where shoreline type, wind, and current data inputs are used by an oil spill simulation model (OSSM) to generate spill trajectory output data (cubes).

Five regional but overlapping sub-models were developed to account for variances within the Puget Sound area: Strait of Juan De Fuca, San Juan Island and Strait of Georgia, North Central Puget Sound, Sinclair Inlet, and South Puget Sound (See Figure 2).

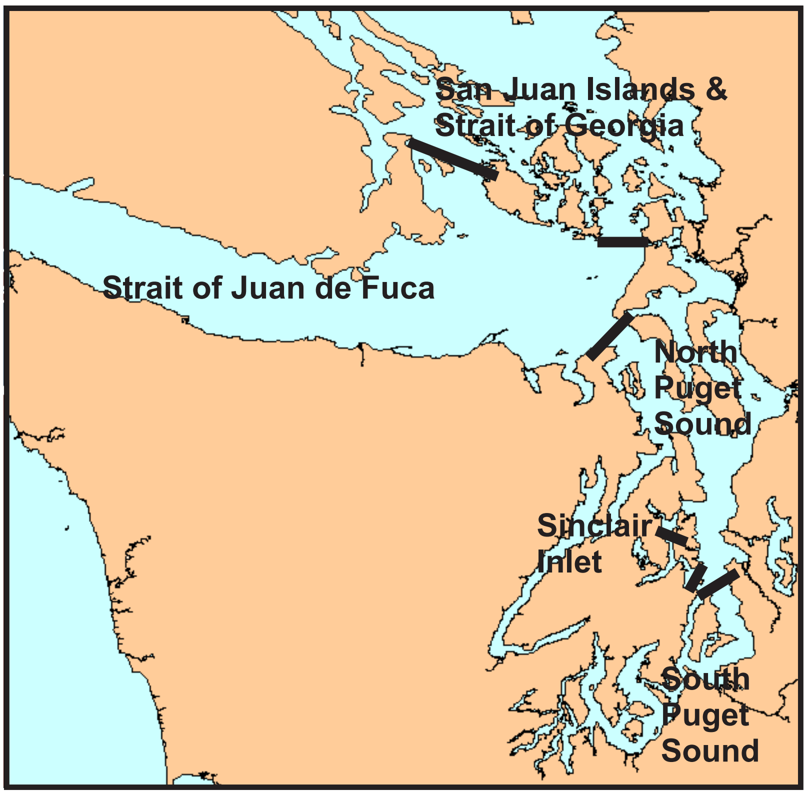


Figure 2. Puget Sound TAP Area and Sub-regions

2.1 Winds

The North Puget Sound region features complex geomorphology and subsequent wind conditions (5). To accommodate this complexity numerous hourly wind records (from several wind stations and for up to 15 years) were used in an interpolation scheme that assumed the contribution from each station was inversely proportional to the distances squared. In some cases duplicate wind stations were simulated to better reflect more prevalent wind conditions of the main Puget Sound basin. This approach was validated through statistical correlation, hindcasting of historic spills, through the professional judgement of local meteorologists, and analysis of Washington State Ferry wind data.

A statistical analysis of the wind records yielded either two or three seasons, depending on the wind station. Based on these statistics and our own experience in the area we chose three seasons: October-March, April-June, and July-September. Figure 3 is an example of a statistical wind table where three seasons were identified. Appendix 1 contains additional examples of statistical wind tables generated seasonally and from multiple year wind data. (Appendix 1 is on the Puget Sound TAP Technical Document disc.)

******* ANNUAL MONTHLY CORRELATION**

For BELLINGHAM AIRPORT

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
JAN	1.00	0.98	0.96	0.85	0.80	0.76	0.73	0.73	0.81	0.92	0.96	0.99
FEB	0.98	1.00	0.96	0.86	0.81	0.77	0.74	0.74	0.83	0.92	0.96	0.98
MAR	0.96	0.96	1.00	0.96	0.92	0.89	0.87	0.87	0.93	0.98	0.98	0.94
APR	0.85	0.86	0.96	1.00	0.99	0.98	0.97	0.96	0.98	0.99	0.94	0.81
MAY	0.80	0.81	0.92	0.99	1.00	1.00	0.99	0.98	0.99	0.97	0.90	0.74
JUN	0.76	0.77	0.89	0.98	1.00	1.00	1.00	0.99	0.99	0.95	0.88	0.70
JUL	0.73	0.74	0.87	0.97	0.99	1.00	1.00	1.00	0.98	0.93	0.85	0.66
AUG	0.73	0.74	0.87	0.96	0.98	0.99	1.00	1.00	0.99	0.92	0.83	0.66
SEP	0.81	0.83	0.93	0.98	0.99	0.99	0.98	0.99	1.00	0.97	0.90	0.76
OCT	0.92	0.92	0.98	0.99	0.97	0.95	0.93	0.92	0.97	1.00	0.98	0.88
NOV	0.96	0.96	0.98	0.94	0.90	0.88	0.85	0.83	0.90	0.98	1.00	0.94
DEC	0.99	0.98	0.94	0.81	0.74	0.70	0.66	0.66	0.76	0.88	0.94	1.00

For a correlation of 0.90 or better the months are grouped as follows:

JAN-FEB-MAR-OCT-NOV-DEC
APR-MAY-SEP
JUN-JUL-AUG

Figure 3. Seasonal Wind Table

San Juan Island and Strait of Georgia

Wind station data used for this region include Smith Island, East Point and Bellingham. Local knowledge and hindcast trajectory analysis of a 1997 Ferndale spill suggest that East Point wind fields are more typical for the Ferndale area than Bellingham winds. Therefore, a duplicate East Point station was added near Ferndale. The resultant hindcast parallels the actual spill trajectory (See Section 4.1.4).

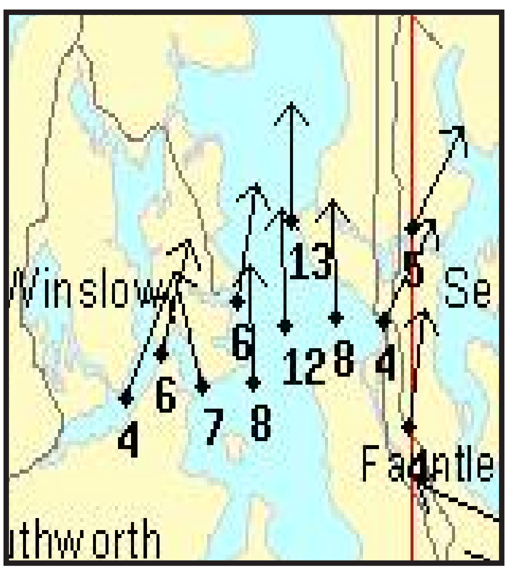


Figure 4. Winds recorded by Washington State Ferry System. Note differences between the greater Puget Sound basin and Sinclair Inlet.

Strait of Juan De Fuca and Haro Straits

Wind station data used for this region included Race Rocks, Port Angeles, East Point, and Smith Island. Nine years of overlapping weather data was available.

North Central Puget Sound

Wind stations used for this region include Paine Field, West Point, NAS Whidbey, and Smith Island. Fifteen years of overlapping weather data was available.

Sinclair Inlet

To be consistent with the general TAP approach several years of wind data are preferred. For the Sinclair Inlet region, however, only three years of wind data were available. Statistical analysis showed that Sinclair Inlet wind conditions were unique from other nearby stations, so it was necessary to include these winds in the Sinclair Inlet regional model (See Figure 4). That Sinclair Inlet winds differ markedly from the nearest wind station, West Point, is not too surprising given the diverse geomorphology. The primary wind station for the

Sinclair Inlet area was located at the southern end of Sinclair Inlet. To temper the wind channeling influence outside the immediate vicinity, a duplicate West Point wind station was artificially created and shifted laterally to the shoreline of Bainbridge Island.

South Puget Sound

Wind stations used for this region include: McChord, Olympia, Tacoma and West Point. Fifteen years of overlapping weather data was available.

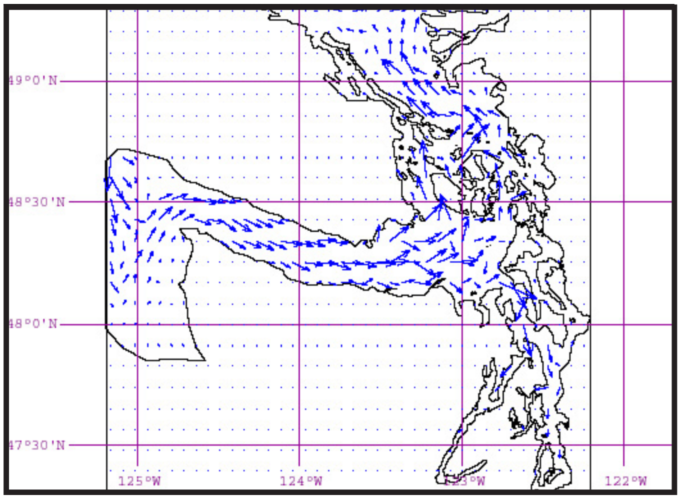


Figure 5. Example of tidal current pattern.

2.2 Currents

Historical tidal currents, river currents, and wind-driven current patterns were computed to complete the geophysical data set that defines the physical processes that move the oil. Current patterns were generated using NOAA/HAZMAT's CATS (Current Analysis for Trajectory Simulations) model[1]. Figure 5 illustrates an example of a current pattern used in the study. Appendix 2 shows the various current patterns used in the study. (Appendix 2 is on the Puget Sound TAP Technical Document disc.)

[1] **WAC and DAC sub-models used**

2.2.1 Tidal Currents

Tidal currents were calibrated using mean maximum flood data from NOS tide tables. There are five regions within the Puget Sound TAP. Each region was calibrated using a tide station within the region. Tidal current regions and their respective calibration tide stations are: San Juan Island and Strait of Georgia (Pt. Lawrence), Strait of Juan De Fuca (Pillar Point), Sinclair Inlet (Rich Passage), North Central Puget Sound (Admiralty Inlet) and South Puget Sound (The Narrows).

In some areas, tidal current patterns generated by CATS were modified to be consistent with NOAA tidal current charts. These areas include Sinclair Inlet, Dyes Inlet, Saratoga Passage, a small area north of Vendovi Island, and the west side of Vashon Island.

Some areas within the Straits of Juan De Fuca were modified to be consistent with Canadian tidal current charts. The quantification of eddy patterns in the Straits of Juan De Fuca is largely unresolved. To date, hydrodynamic modeling and drift card studies have not fostered consensus among oceanographers regarding the predictability of eddy patterns, the physical processes generating eddy patterns, or whether distinct eddy patterns can be distinguished from generalized turbulence. Upon review of available data and discussion with leading authorities[2], it was decided that the most reasonable approach would be to adopt eddy patterns similar to those

suggested in the *1983 Canadian Tidal Current Atlas for Strait of Juan De Fuca and Strait of Georgia*. (2)
[2]*Discussions with Barbara Hickey (University of Washington) and Curt Ebbesmeyer (Evans-Hamilton, Inc.)*

Four current patterns used in the San Juan Strait region include: a tidal pattern, a pattern for the local circulation in the Port Angeles area and one pattern each for the flood and ebb tide induced eddies. Currents between Port Angeles and Dungeness Spit were calibrated to a significant 1985 Port Angeles spill and drift card studies (4,6). Additional details documenting the formulation of eddy patterns can be found in the NOAA technical document titled *General NOAA Oil Modeling Environment (GNOME™) Strait of Juan de Fuca Location File User's Guide (10).*

2.2.2 Wind Driven Current

A wind driven coastal current was modeled along the eastern side of the Straits of Georgia. The current was driven by the NNW component of the winds from East Point. This current was based on field observations and scaled such that a 10-knot wind from the NNW resulted in a 0.1-knot current off Cherry Point (12).

2.2.3 River Currents

Flow from the most dominant rivers in Puget Sound was modeled: Fraser, Nooksak, Stillaguamish, Snohomish, Skagit, Elwha, Duwamish, Puyallup, and Nisqually (5). Historic flow data (1984-1998) was used to create daily current patterns for each river's flow. A freshwater lens was taken into account when generating river current patterns. (2,3,7,13,15) With the exception of the Elwha and Fraser Rivers, currents were modeled to rapidly die out once beyond waterway mouths.

The extent of the Fraser influence is known to be significant (1,2,3,8). This influence varies greatly and is dependent on a number of factors, e.g. flow varies greatly from a few hundred cubic meters per second (CMS) to over 10,000 CMS. Since this broad influence is seasonal (13), the Fraser current was only modeled during high flow months of May, June, July, and August. The approximate dimensions of the Fraser were based on a compilation salinity, suspended sediment, and bathymetric data (1,2,3,8). The approximate width of the observed fronts was used to estimate the horizontal component of the cross sectional area. Surface velocities decreased as the width of the cross section area increased.

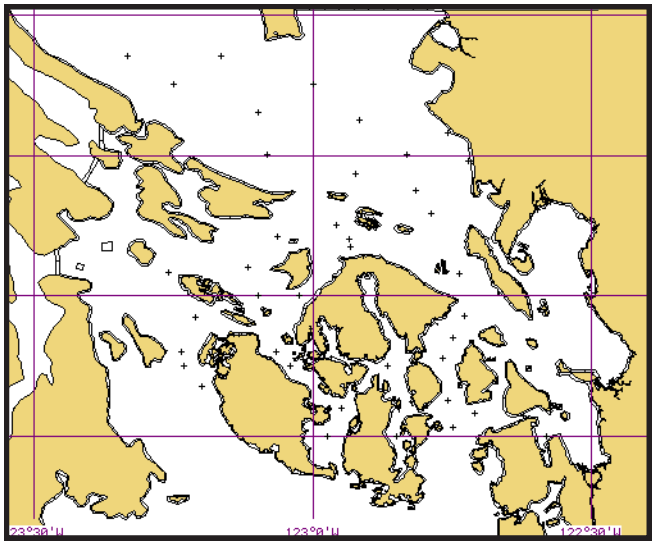


Figure 6a. Spill sites (+) in San Juan Islands and Strait of Georgia sub-region.

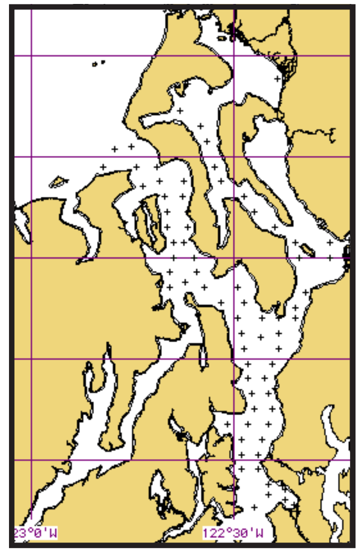


Figure 6b. Spill sites (+) in North Puget Sound sub-region.

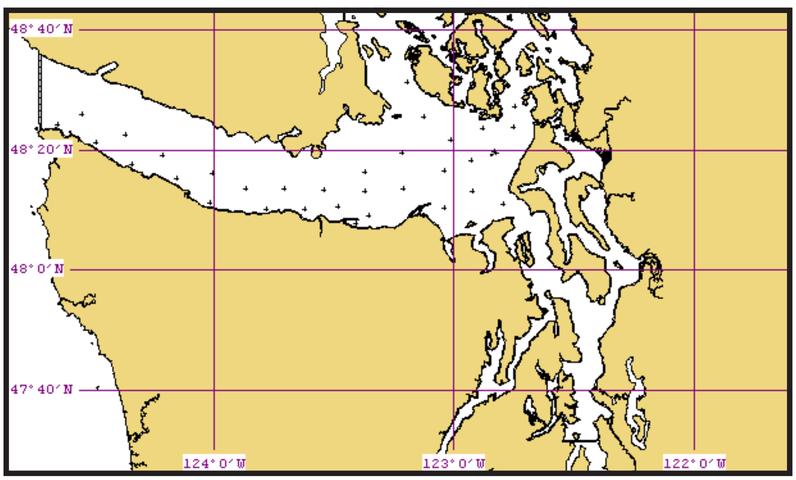


Figure 6c. Spill sites (+) in Strait of Juan de Fuca sub-region.

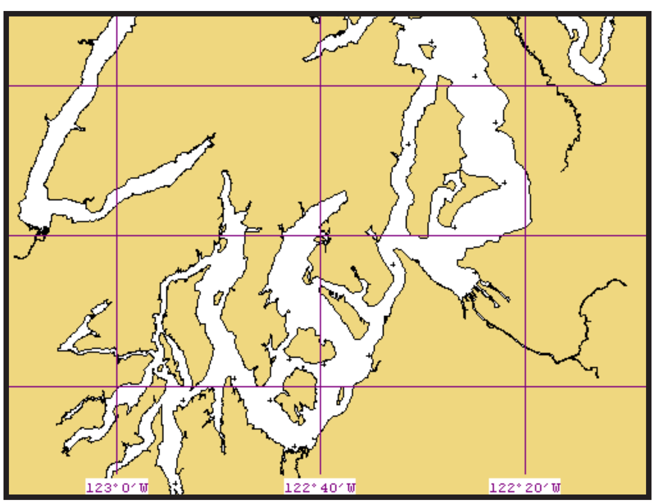


Figure 6d. (Spill sites (+) in South Puget Sound sub-region.

2.3 Spill Sites

Approximately 200 spill sites were used for the Puget Sound TAP (See Figures 6a, 6b, 6c, 6d). 500 independent spills were modeled and analyzed for each spill site and each season. Start sites were chosen near regulated facilities, along major shipping lanes, and in known areas of higher risk (11).

2.4 Receptor Sites

Shoreline areas of the Puget Sound TAP are divided into approximately 2000 separate segments of approximately two kilometers in length by 0.5-0.75 kilometers in width. This represents the shoreline resolution used by each TAP run (See Figure 7 on next page). TAP calculates the probability of intersecting these receptor polygons, based on 500 modeled trajectory runs. (When using the TAP program, run the cursor over the receptor polygon to view the site number.)

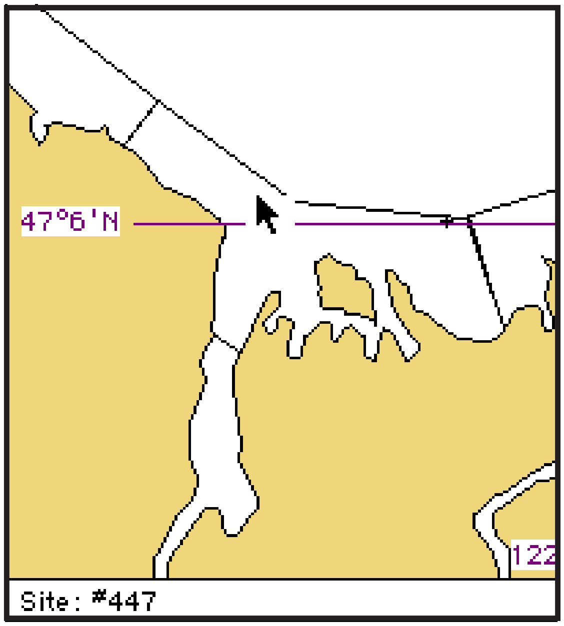


Figure 7. Example of receptor polygons.

3 ON-SCENE SPILL MODEL (OSSM)

NOAA's On-Scene Spill Model (OSSM) was used to simulate individual spill trajectories. (14) TAP statistics are generated from a compilation of OSSM trajectory runs. OSSM was used in a batch mode to randomly select and loop through 500 independent trajectory runs for each start site, for each of the three seasons.

3.1 Details of Trajectory Runs

3.1.1 Random Start Times

Hourly wind records were scanned for potential start times. An acceptable start time was defined as any 48-hour record within the data that had no gaps larger than six hours. The actual start hours were randomly selected from the resulting list of acceptable start times.

3.1.2. Trajectory Runs

500 OSSM trajectory runs were completed for each site and each season. For the Puget Sound TAP this represents approximately 300,000 individual runs (200 sites x 3 seasons x 500 spills). OSSM simulates the spread and flow of oil through the modeling of individual spill particles or Lagrangian Elements (LEs). Each run was initialized with 1000 LEs. For each run when an LE path intersected a receptor site, the time of the hit was recorded and a corresponding data file created.

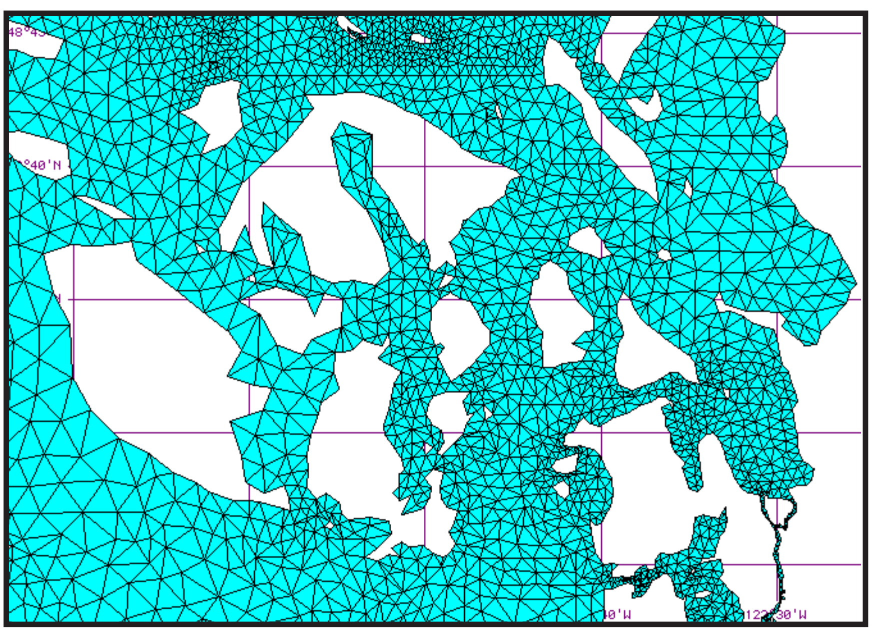


Figure 8. Example of triangle grids around San Juan, Orcas and Lopez Islands.

3.1.3 The Run Parameters

Each model run went for two days with a computational time step of 0.25 hours. A random walk diffusion was used that allowed each particle to move in a random direction of 0.21 km to 0.3 km every .25 hours. The model used over 12,000 bathymetry points and a finite element triangular mesh with thousands of triangles to generate the current fields. The grid lengths of each triangle varied with location and ranged between 100 and 1200 meters. Figure 8 illustrates an example of a grid.

3.1.4 Model Shoreline

Rectangular boxes composed the model shoreline used for beaching and refloating. Each box was assigned one of six shoreline types, which defined how quickly oil could refloat from the beach. The refloating half-life for different types of shorelines ranged from one hour to 8760 hours. The shoreline was mapped into rectangles ranging from 100 to 400 meters per side.

4 Accuracy of TAP

While the Puget Sound TAP is intended to be accurate to the maximum extent practicable, it is acknowledged that higher accuracy may be achieved as knowledge and technology improve. The greatest strength of the TAP approach is the large number (thousands) of scenario possibilities considered. Minor step errors that lead to gross error for individual trajectories are likely bypassed through the slightly different paths of hundreds of scenarios, and overall trends should be more accurate than individual trajectory results.

Uncertainty

As discussed in Section 4.2, TAP and the underlying trajectory model, OSSM, do have limitations regarding accuracy. NOAA's approach for determining confidence bounds of individual trajectory runs is somewhat subjective and case by case. Therefore, it is not feasible to apply confidence bounds to overall calculated probabilities, given the hundreds of scenarios analyzed.

Perhaps the best way to ascertain accuracy is through investigating actual events and comparing with OSSM's predicted results. Section 4.1 discusses OSSM's accuracy at predicting the trajectory of historical spill events. Section 4.2 discusses accuracy limitations of OSSM and the TAP approach.

4.1 Hindcast Trajectory Comparison with Historical Spill Events

Hindcasting can be used as a means to qualitatively (and to some extent quantitatively) assess the accuracy of the spill modeling components. Ideally, from a modeling perspective, there would be dozens of major spills to investigate. Unfortunately, from a modeling perspective, there have been few major spills within the Puget Sound Region. Further, documentation of existing spills is frequently not detailed enough to foster meaningful comparison. A hindcast trajectory comparison is offered in the next pages for the following historical spill events: 1985 Port Angeles (239,000 gallons) *see pages 16 and 17*; 1990 Point Wells (3000 gallons) *see pages 18 and 19*; 1991 Fidalgo Bay (820,000 gallons) *see pages 20 and 21*; 1997 Ferndale (2000 gallons) *see pages 22 and 23*.

4.1.1 - 1985 Port Angeles Spill (239,000 Gallons - Alaska North Slope Crude)

On December 21, 1985 at 1630 hours, approximately 239,000 gallons of Alaska North Slope Crude was spilled as a result of the grounding of the ARCO ANCHORAGE. An over-flight report (Figure 10) was obtained from NOAA HAZMAT files.

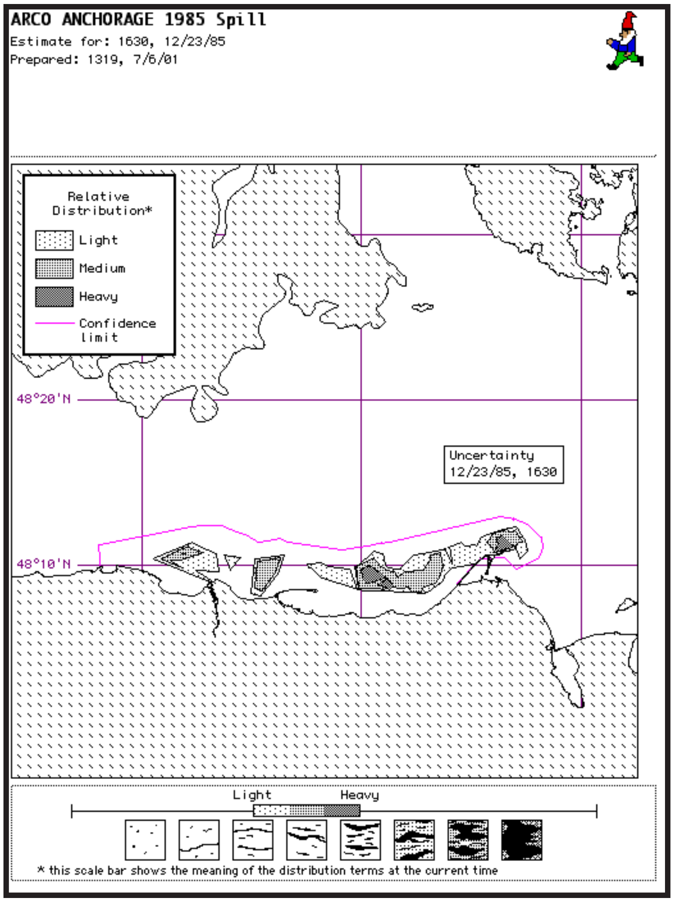


Figure 9. Hindcast confidence bounds for Port Angeles 1985 spill (48 hours).

The over-flight report is from December 23, 1985 or 48 hours into the incident. During the spill event, product nearer the shoreline migrated eastward toward Dungeness Spit, while product farther out migrated westward as far as the mouth of the Elwha River. Corresponding to the over-flight report is the OSSM hindcast (Figure 11). In this case, hindcast appears to closely mirror the historic spill event. [This spill was used to help calibrate the current pattern for the area.] Figure 9 shows that oiled areas are within the predicted bounded areas and confidence interval.

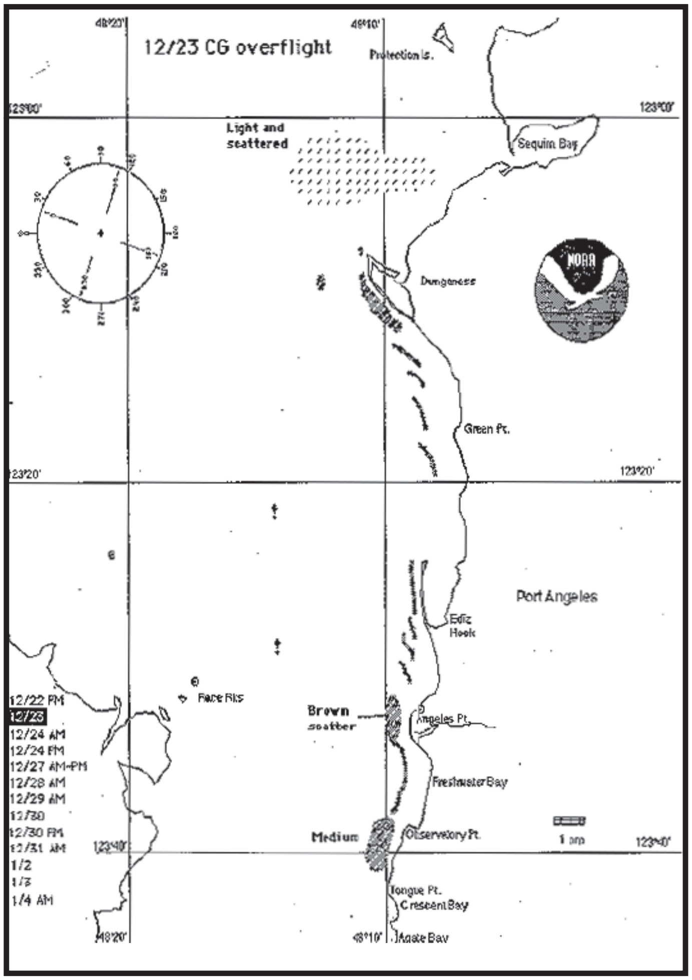
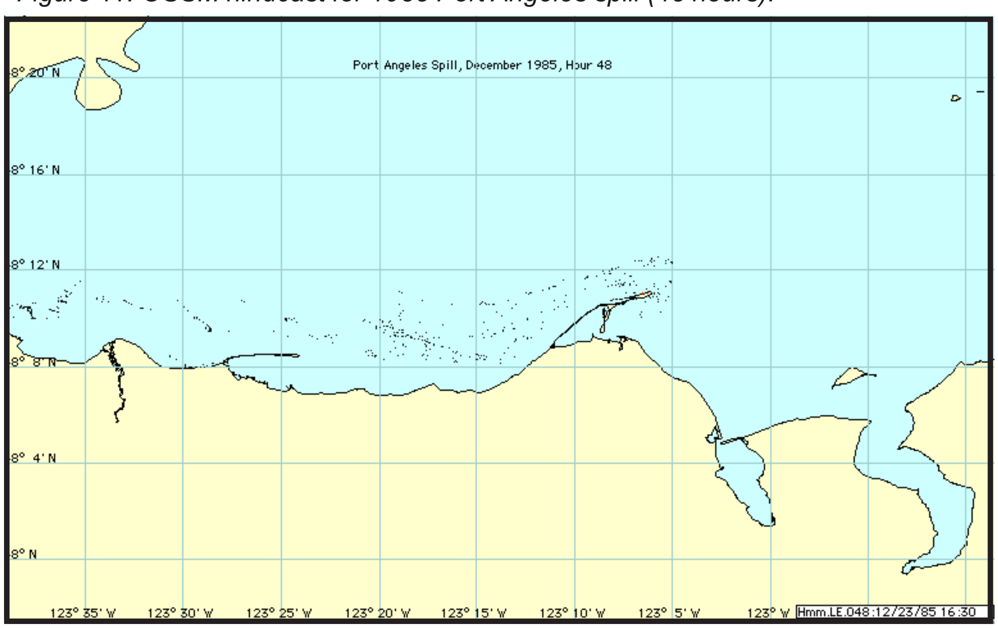


Figure 10. Overflight report for 1985 Port Angeles spill (48 hours).

Figure 11. OSSM hindcast for 1985 Port Angeles spill (48 hours).



4.1.2 - 1990 Point Wells Spill (3,000 Gallons - NW Charge stock)

On August 30, 1990 at 2300 hours, approximately 3000 gallons of NW Charge Stock was spilled into Puget Sound from an asphalt refinery located at Point Wells. The cause of the spill was a tank overflow. An over-flight report (figure 12) was obtained from Washington State Department of Ecology files.

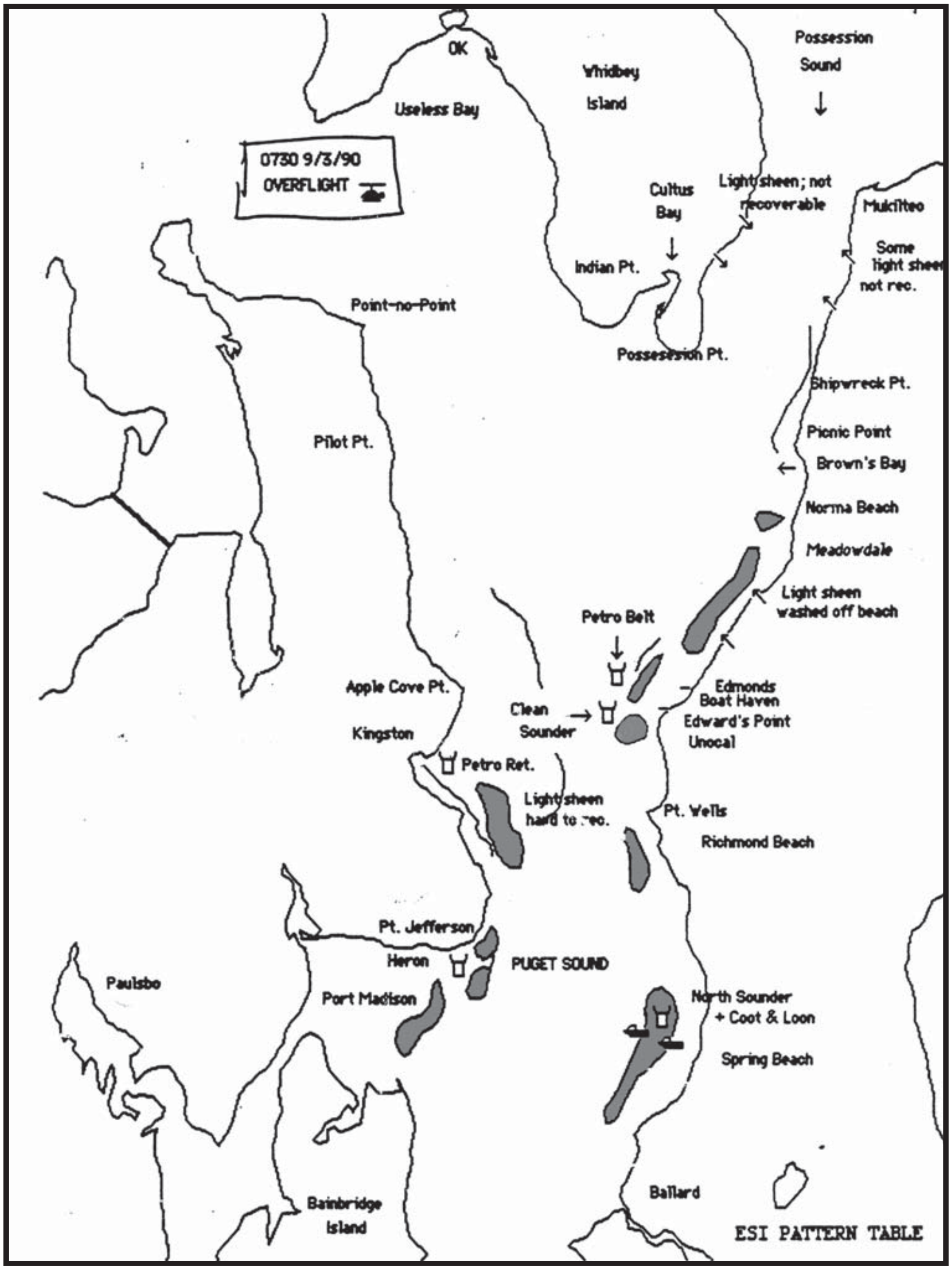


Figure 12. Overflight report for 1990 Point Wells spill (81 hours).

The over-flight report is from September 3, 1990 at 0730, or three days and nine hours into the incident. Shoreline impacts were observed on the eastern side of Puget Sound from Pt.Wells north to Possession Sound. Skimming operations occurred in open-water oiled areas off Kingston, Pt. Jefferson, Spring Beach, and Edwards Point.

Corresponding to the over-flight report is an OSSM hindcast (figure 13). There is fairly good agreement between the hindcast and the historic spill event. In both cases, oiled areas occur on both sides of Puget Sound from Spring Beach north to Possession Sound. The hindcast predicts less oiling off Jefferson Pt. and north of Bainbridge Island than was actually observed. Figure 13 shows that oiled areas are within the predicted bounded areas and confidence interval.

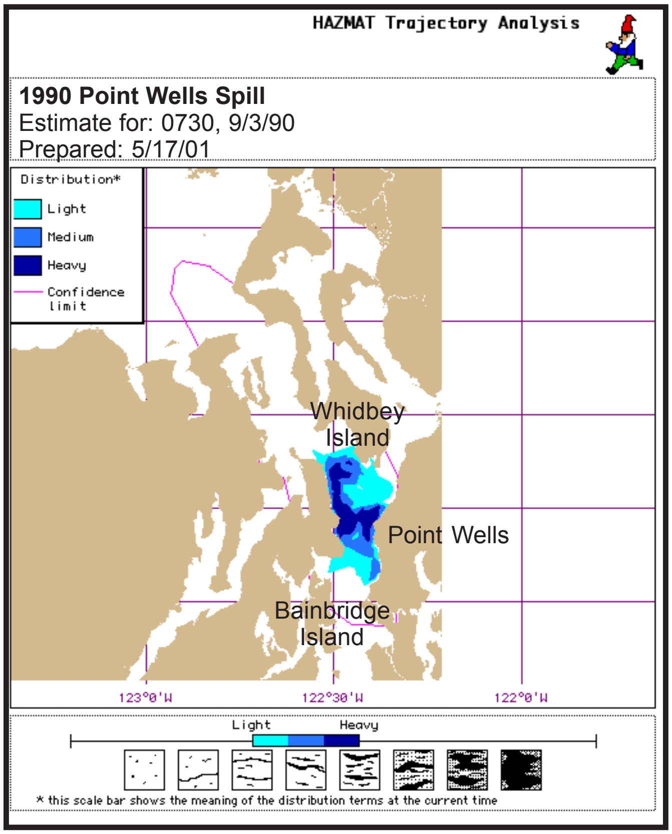


Figure 13. Hindcast trajectory and confidence bounds for 1990 Point Wells spill (81 hours).

4.1.3 - 1991 Fidalgo Bay Spill (840,000 Gallons - Alaska North Slope Crude)

On February 22, 1991 at 2200 hours, a pipeline rupture spilled 20,000 bbls (840,000 gallons) of Alaska North Slope Crude into Fidalgo Bay. An over-flight report was obtained from NOAA/HAZMAT.

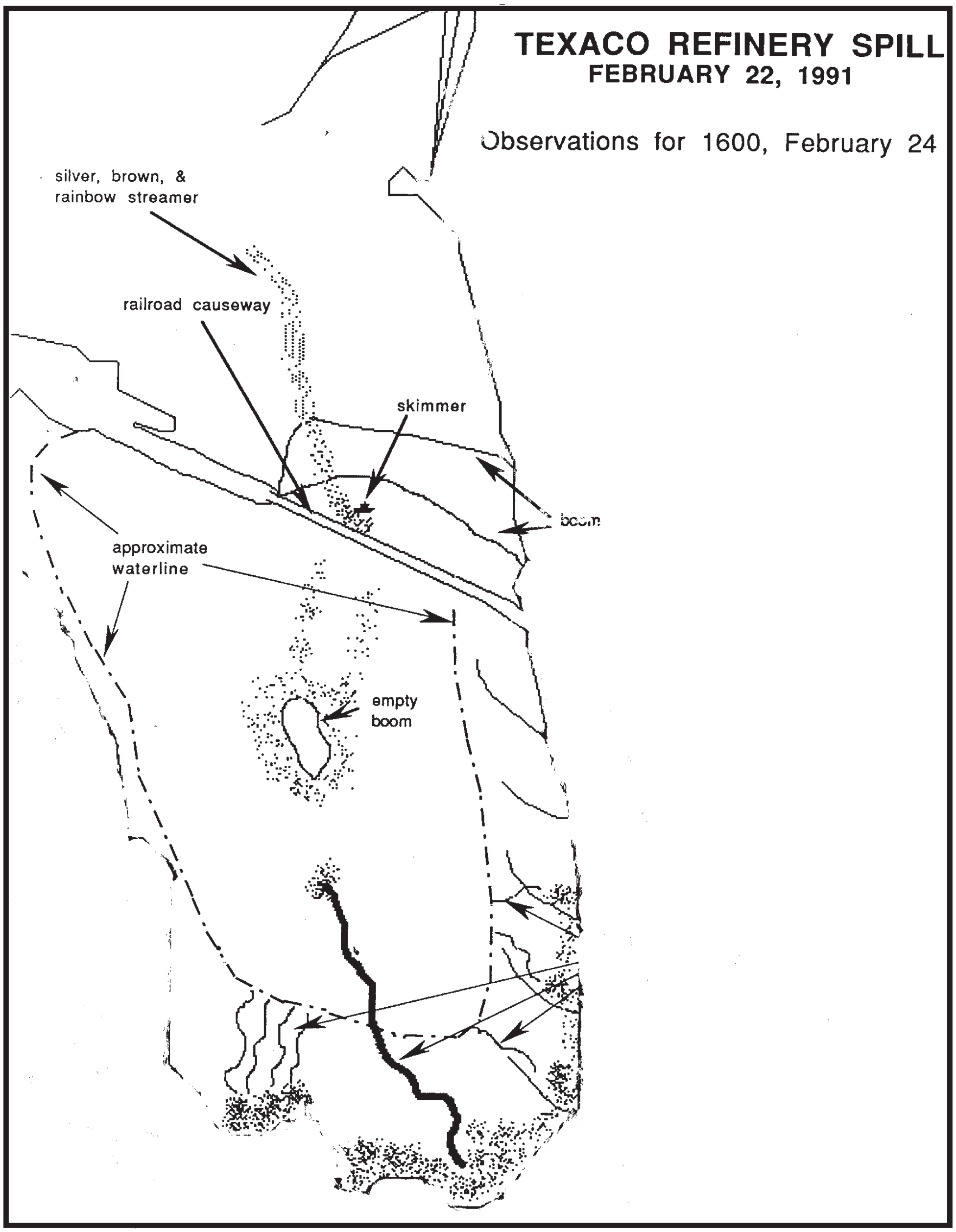


Figure 14. Overflight report for 1991 Fidalgo Bay spill (37 hours)

The over-flight report (figure 14) is from February 24, 1991 at 1100 hours. At this time heavy oiling was reported at the southern end of Fidalgo Bay. It should be noted that booms were placed around much of the area and heavier concentrations of product, and only small quantities of product spread beyond Fidalgo Bay.

Corresponding to the overflight report is the OSSM hindcast (figure 15). In this instance, there is fairly good agreement between the hindcast and the historic spill event. Heavy impacts were observed within Fidalgo Bay in both cases. The hindcast shows that a considerably larger area might have been contaminated were it not for boom containment and recovery efforts.

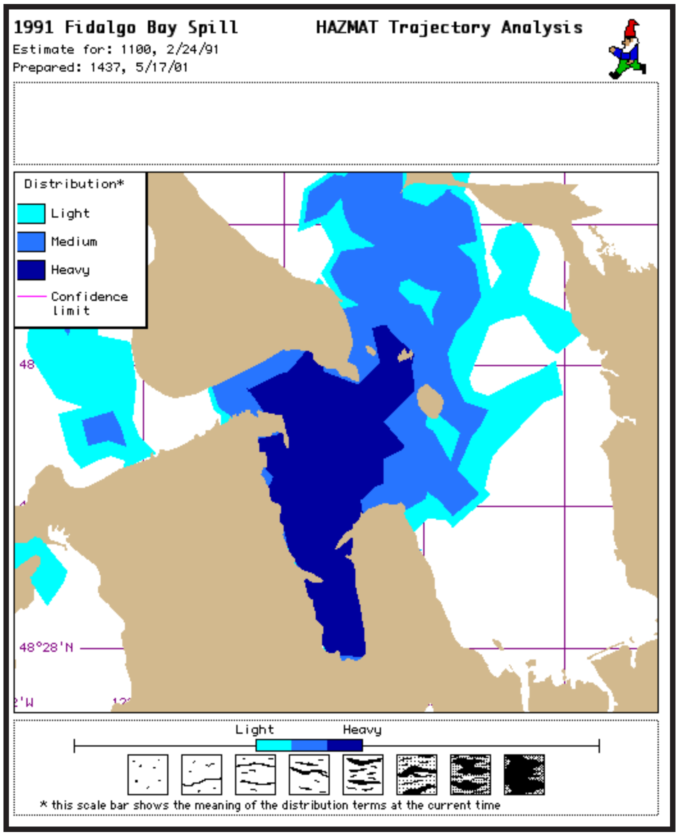


Figure 15. Hindcast trajectory for 1991 Fidalgo Bay spill (37 hours).

4.1.4 - 1997 Ferndale Spill (2,000 Gallons - Marine Fuel Oil)

On August 5, 1997 at 2200 hours, a fuel transfer error at a refinery near Ferndale led to a spill of approximately 2000 gallons of marine fuel oil into the Strait of Georgia. The cause of the spill was operator error during a fuel line purging procedure. An overflight report was obtained from Washington State Department of Ecology files (Figure 16). The report represents a composite trajectory from numerous overflight observations.

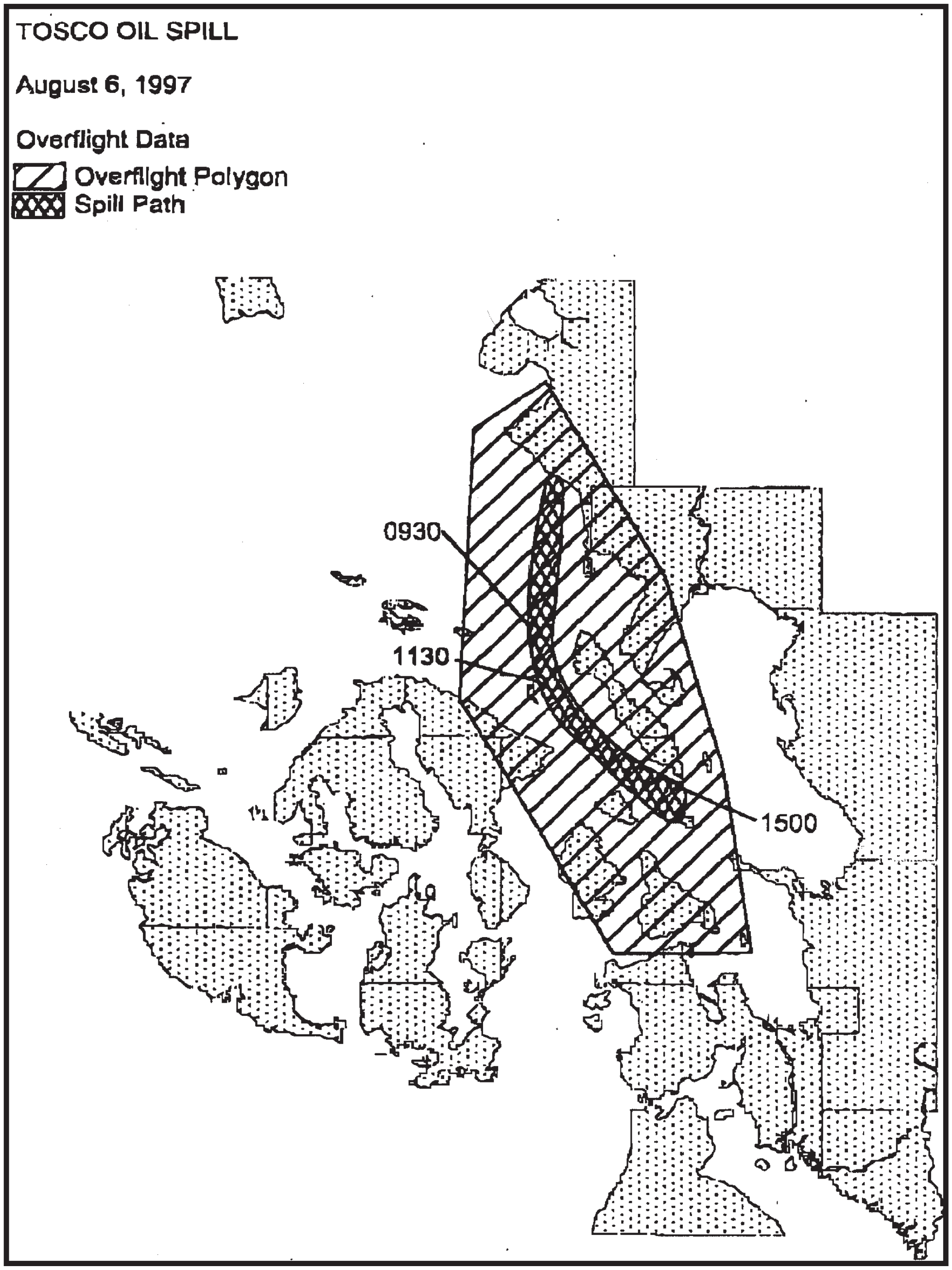


Figure 16. Overflight report for 1997 Ferndale spill (composite through hour 42).

A composite OSSM hindcast shows predicted impacts for same time frames as the overflight observation (Figure 17). In this instance, there is fairly good agreement between the hindcast spill path and the historic spill path. [The actual spill migrated farther south than predicted.]

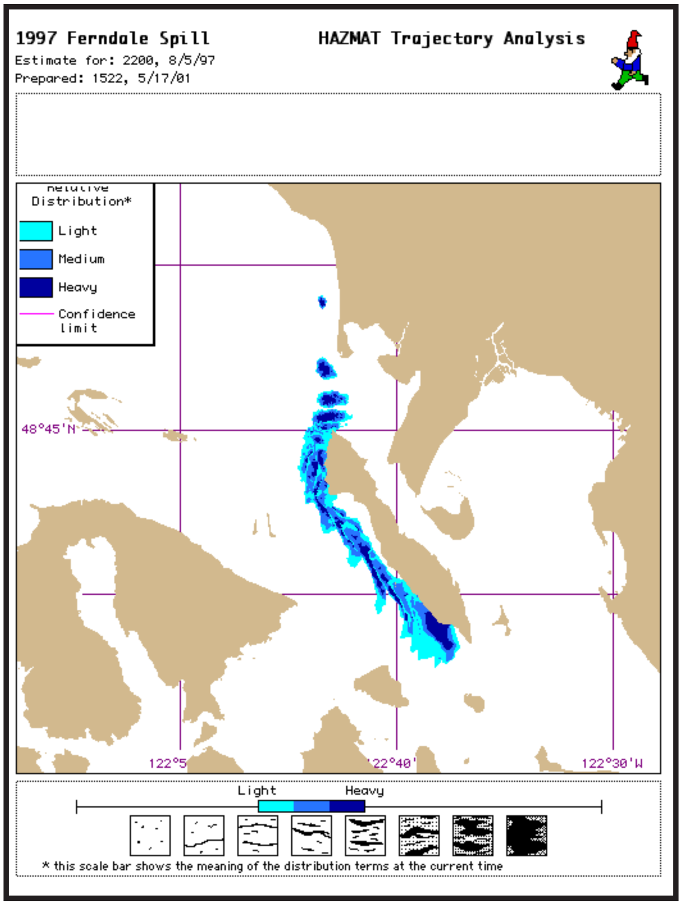


Figure 17. Hindcast trajectory for 1997 Ferndale spill (composite through hour 42).

4.2 ACCURACY LIMITATIONS

The TAP's most basic limitation is the accuracy of the assumption that spill impact probabilities generated by past weather and oceanographic conditions are indicative of future probabilities. This section discusses three additional types of limitations: computational time limitations, trajectory limitations and concentration limitations.

Computational Time Limitations

Computational time restraints for spill modeling required a reasonable but finite number of Lagrangian Elements (LEs), model grids, timesteps, and spill simulations. (It took approximately 600 computer-days to run the computations for the Puget Sound TAP.)

Trajectory Limitations

The accuracy of predicted spill trajectories is not constant. Timing and location influence trajectory accuracy. TAP will be most accurate where model assumptions correspond well in space and time with actual conditions.

Trajectory Accuracy Dependent On When Spills Happen

Winds are resolved to one reading per hour. Singular hourly wind readings may or may not be indicative of the actual wind conditions. Accuracy will be higher when hourly readings are indicative of actual wind conditions.

River currents are resolved to a single reading (average daily flow). Accuracy will be higher when the average daily flows are indicative of the actual flow conditions. River systems subject to large hourly fluctuations in flow are especially susceptible to this sort of inaccuracy.

This model does not take into account episodic widespread effects such as major incursions from the Pacific into the Strait of Juan de Fuca and North Puget Sound. The accuracy of the model would be adversely affected when random spill times occur during one of these events.

Trajectory Accuracy Dependent On Where Spills Happen

The accuracy of wind condition projections depends on the spill site location. Winds were interpolated between stations. Although this scheme may accurately depict wind conditions for the greater Puget Sound basin, it is unlikely to address localized wind conditions resulting from complex topographic features. Where well documented, efforts were made to account for unique wind conditions. Additionally, an analysis was done comparing Washington State Ferry wind data with predicted winds. The analysis of more than 130,000 individual records during a four week period (April-May 2001) showed that the overall mean wind speed and direction versus that predicted by the wind station interpolation scheme used in the model is fairly good overall and in most areas (See Figure 18).

As expected, relative errors were greatest where wind channeling was likely, e.g., Sinclair Inlet and San Juan Island areas.

Ferry Run	*Mean Wind Speed (knots)*	*Average Direction*	*Predicted Wind Speed*	*Predicted Direction*
All runs	10	188	11	194
All runs out of Seattle	12	149	10	141
Edmonds to Kingston	12	110	10	170
Runs across Rosario Strait	12	220	12	190
Runs across Admiralty Inlet	14	237	13	214

Figure 18. Comparison of Wind Data (Ferry Observations vs. Predicted Observations)

Tidal currents were calibrated using mean maximum flood data from NOS tide tables. There were four designated regions within the North Puget Sound TAP. Since each region was calibrated using a single tide station within each region, tidal lags of up to an hour may not be reflected in some areas. Accuracy increases or decreases depending on how closely a spill site's tidal profile matches that of the calibrating tide station.

The models used for the currents did not include any nonlinear advective terms. For each area modeled, a single generalized diffusion rate assumption was used to simulate turbulent spreading. The accuracy of results yielded by this assumption will vary over time and space.

Currents driven by freshwater runoff from major rivers are included in the spill model. Outflow from rivers results in a tendency to keep oil offshore. Subsequently, TAP may over-predict shoreline impacts in areas where streams and small rivers are not included in the models. This impact on overall accuracy is minimal given the resolution of the models.

The interactions of spilled substance with suspended sediment and floating biota were ignored. Owing to a reduction in wind driven behavior, shoreline impacts may be overestimated in areas where vegetation such as floating eelgrass mats is present. For large spills, accuracy of concentration may be more at issue than that of trajectory, since eelgrass has a finite capacity to adsorb spilled product (9).

Additional limitations affecting trajectory resolution include: 1) a 15-minute computational time step; 2) computational current grid size (triangle lengths from about 100 to about 1200 meters); and 3) shoreline beach type grid size (squares from about 100 meters to 400 meters per length).

Concentration Limitations

Even if the overall or approximate trajectories are accurate, the ability to translate LE movement into concentration values is limited. Factors limiting the ability to predict concentration include: model grid sizing, the LE versus fluid approximations, and weathering approximations.

Receptor Site Size

Receptor sites were resolved to an area approximately two kilometers in length by 0.5-0.75 kilometers in width. Many areas of concern are smaller than this; thus, TAP may overstate the concentration to these areas. Smaller receptor sites might actually lead to underestimating concentration, especially in cases where the size of the receptor cell far exceeds the likely trajectory resolution.

Shoreline Type and Grid Size

The number of LEs and concentration of impacts at subsequent locations was dependent upon whether oil refloats. OSSM's ability to accurately depict refloating oil was limited because of the following: 1) refloat potential was generalized by half-life algorithms per shoreline type; 2) shoreline types were generalized to include only six shoreline types; and 3) in some areas shoreline type was generalized into grids too large to resolve actual shoreline types.

Lagrangian Elements (LEs) vs. Surface Spreading Behavior

TAP assumed that the type or amount of oil spilled did not determine the spreading on the water surface. The more LEs used in a model, the more accurately the model can reflect surface spill behavior, especially for larger spills. The larger the spill volume the less resolution each LE represents. Greater inaccuracies may occur when trying to predict impact concentrations where a relatively low level of concern is coupled with a relatively high spill volume. For example, TAP doesn't resolve any difference in probabilities between a 1000-barrel spill with a one-barrel level of concern and a 10,000-barrel spill with a one-barrel level of concern.

Weathering

The amount of oil predicted to come ashore depends largely upon the evaporation/ dispersion rate of the oil. Oil weathering was calculated using simplified oil-fate equations, which are applied when the user chooses "oil type."(14) Accuracy of weathering predictions is dependent on any of a number of factors that influence mixing energy and evaporative exposure.

5 Bibliography

(1) Baker, E.T., Cline, J.D., Feely, R.A., Quan, J. 1978. *Seasonal Distribution, Trajectory Studies and Sorption Characteristics of Suspended Particulate matter in the Northern Puget Sound Region.* EPA-600/7-78-126.

(2) 1983. *Canadian Tidal Current Atlas for Strait of Juan De Fuca to the Strait of Georgia.* Canadian Hydrographic Service. 1983

(3) Cannon, GA 1978. *Circulation in the Strait of Juan De Fuca.* NOAA Technical Report ERL-PMEL 29

(4) Cox, Jefferey M., Ebbesmeyer, C. (1980). *Drift Card Observations in Northwestern Washington Along Portions of 'Two Proposed Oil Pipeline Routes.* Office of Environmental Engineering and Technology Office of Research and Development U.S. Environmental Protection Agency.

(5) Downing, J.D. (1983). *The Coast of Puget Sound its Processes and Development.* A Washington Sea Grant Publication Distributed by University of Washington Press Seattle and London.

(6) Ebbesmeyer, Curtis C., Cox, Jefferey, Helseth, M., Jonathon, M., Heinchey, Lawrence R., and Thomson, David W. (1979). *Dynamics of Port Angeles Harbor and Approaches, Washington.* EPA-600/7-79-252.

(7) Fischer, H.B. et al 1974. *A Numerical Model of Material Transport in a Salt-Wedge Estuary.* United States Department of the Interior Geologic Survey.

(8) Freeley, R., Lamb, F.L. (1979). *A Study of Dispersal of Suspended Sediment from the Fraser and Skagit Rivers into Northern Puget Sound Using Satellite Imagery.* EPA-600/79-165.

(9) Mora, D.G., Challenger, G. (1999). Resolving Conflict in Applying the Washington State Natural Resource Damage Assessment Compensation Schedule - Spill Volume Determination in the Absence of Volumetric Methods. *1999 Proceedings of the International Oil Spill Conference.*

(10) NOAA. 2001. *General NOAA Oil Modeling Environment (GNOME™) Strait of Juan de Fuca Location File User's Guide.* Seattle: Hazardous Materials Response Division, National Oceanic and Atmospheric Administration. 7 pp.

(11) National Center Associates. (2000). *North Puget Sound Long Term Oil Spill Risk Management Panel - Final Report and Recommen-dations.* Washington Department of Ecology, #00-08-024. Appendix 14.

(12) Schumacher J.D., C.A. Pearson, R.L. Charnell, and N.P. Laird. (1978). Regional Response to Forcing in Southern Strait of Georgia. *Estuarine and Coastal Marine Science.* 7:79-91

(13) Tidal Current Tables 2001 Pacific Coast of North America and Asia (2000). *International Marine,* Cambden, Maine.

(14) Torgrimson, G.M. (December 1984). *The On-Scene Spill Model.* NOAA Technical Memorandum NOS OMA 12, Rockville, Maryland.

(15) Waldechuck, M., 1957. Physical Oceanography of the Strait of Georgia British Columbia. *J.Fish.Res.Bd.* Canada, 14:321-486

6 APPENDICES

See CD - *Puget Sound Trajectory Analysis Planner (TAP) Technical Documentation, software, User Guide and Appendices (July 2003). Ecology publication number: 03-08-008.*

Appendix #1: Wind Correlation Matrix and Statistical Tables
(Available in PDF format on CD)

Appendix #2: Tide and Current Patterns
(Available in PDF format on CD)

Appendix #3: Computational Triangle Grids
(Available in PDF format on CD)

Puget Sound Trajectory Analysis Planner (TAP)
Technical Documentation